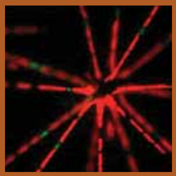
3 National Parks as Laboratories and Frontiers for Knowledge

Our national parks are tremendously important not only for their recreational values but also as natural laboratories. As exquisite expressions of biological,



physical, historical, and prehistoric diversity, they hold great potential for untold fascinating and meaningful discoveries about our world and our role in its stewardship. Their status as protected, lesser-disturbed, and stably administered sites suits them particularly well for inquiry, and their value as frontiers for knowledge only increases as unprotected areas become ever more fragmented. The articles in this chapter expand on these themes, in particular detailing progress in documenting park biological diversity. Through productive partnerships that use both traditional and state-of-the-art inventory techniques, scientists are discovering new life-forms and recording new species for parks, information that both is useful for park management and adds significantly to our understanding of the world. One technique, genetic sequencing, is being used

with great success to analyze an astonishing array of life-forms from Yellowstone Lake. Some of these activities are valuable also for their involvement of the

public as citizen scientists in documenting life and learning about parks through hands-on science. Other activities reported herein highlight the value of parks as places to study resource disturbance and recovery and to refine research methods. The following articles illustrate a few of the superior opportunities national parks afford as laboratories of nature.

> *"As change throughout the world accelerates, as park data bases are developed, and field research facilities expanded, the value of parks for science appreciates beyond measure."* — **National Research Council**

Molecular approach to biodiversity inventory doubles list of known species in Yellowstone Lake

By John D. Varley

BIOLOGICAL DIVERSITY IN YELLOWSTONE LAKE is much richer and broader than scientists have previously concluded. Collecting community DNA and separating 16S and 18S genes for sequencing, researchers participating in a pilot Molecular All Taxa Biodiversity Inventory (MATBI) have identified more than 251 new species for the lake since 2004, nearly double the amount known previously. Just two of the species inventoried in the MATBI were known from earlier species lists, and the new discoveries belong to all three domains of life. More species will be identified in the future as longer-term analytical techniques are completed.

Despite 135 years of near-heroic efforts to classify life in Yellowstone Lake, scientists using All Taxa Biodiversity Inventory (ATBI) techniques had documented just 263 species and had generally concluded that the lake is a "simple ecosystem." Thus the chance to compare the existing taxonomic list of species and genera from ATBIs with a cutting-edge genomics survey of species was an irresistible opportunity to improve scientific knowledge of this unusual, high-elevation lake.

One species … has never been observed outside its Antarctic habitat, and another has never been found outside its unusual home in an oxygen-deficient basin in the Caribbean Sea.

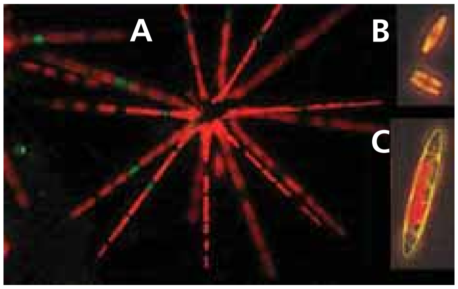
The MATBI was initiated in 2004 as a proof-of-concept trial to evaluate its potential for determining the eukaryotic, bacterial, and archaeal biodiversity within Yellowstone Lake. The National Park Service (NPS), the Gordon and Betty Moore Foundation, Diversa Corporation, Eastern Oceanics, Inc., the US Geological Survey, and the Yellowstone Park Foundation funded and collaborated on the project. In this pilot study, researchers used standard methods to sample "normal" cold-water subalpine aquatic habitats and submerged geothermal sites from boats, by scuba divers, and by remotely operated vehicles. However, the ability to separate a mixture of community DNA into coherent parts that can be sequenced and analyzed is what sets this inventory technique apart from other molecular analysis work.

Domain Archeabacteria was populated for the lake for the first time, with 103 species, including several clusters that appear to be new to science. Identified separately was the newly discovered group Nanoarchaea, which increased the worldwide number of species from a single named species to about 28 unnamed lineages. The new species reported here are the first freshwater records of the group. In domain Eubacteria, the lake's known species jumped by 71 new additions, and in domain Eukarya, the number of known species increased by 28 forms.

Qualitatively, the newly identified species were a curious lot, ranging from the common to the unbelievable. In domain Eukarya, for example, researchers expected species typical of the lake's subalpine and nutrient-poor character, and indeed one species assemblage was indicative of that type and similar to species in the Laurentian Great Lakes, Siberia's Lake Baikal, and several high-elevation lakes in the Andes Mountains. But they also found marine organisms, species known only from rivers and streams, and still others that are indicator species for nutrient-rich or polluted waters. Until now, one species found has never been observed outside its Antarctic habitat, and another has never been found outside its unusual home in an oxygen-deficient basin in the Caribbean Sea.

Inventorying a park's biodiversity is a bigger job than many people realize. First, most of the easily identified species have already been named, leaving the hard ones still to be done. One park biodiversity expert believes that 99% of the park's microbes and 75% of its invertebrates remain undiscovered. Second, using centuries-old techniques like Linnaean taxonomy—as valuable as it is—simply takes too much time and expertise to make inventory completion feasible. Newer techniques are sorely needed. Knowing what each park has in terms of its biodiversity got a big boost in 1998, when Congress reinforced the importance of species inventories as part of the NPS mission. The inventory program has been supported with "new money" from the Natural Resource Challenge initiative, and progress has been made in a portion of the parks, including Yellowstone. But managers are still far from knowing even 50% of the total species in any park.

NPS fisheries biologist Phillip Doepke and Eastern Oceanic's Dave Lovalvo prepare to deploy the remotely operated vehicle (ROV) from the research vessel *Cutthroat* on Yellowstone Lake. The ROV was fitted with a bucket sampler for the Molecular All Taxa Biodiversity Inventory and used to scoop life-rich soil samples from a geothermal feature on the floor of Yellowstone Lake.



Diatoms are among the many life-forms discovered in the MATBI of Yellowstone Lake. Cultured in a laboratory in San Diego, California, *Asterionella formosa* is shown in A. The red fluorescence corresponds to chloroplasts, the green to the nuclei when excited with blue light. Two additional diatoms (B and C) have no affinity to known diatoms in the GenBank database.

The study participants believe the pilot MATBI on Yellowstone Lake can now be considered a new biodiversity assessment model, melding classic Linnaean taxonomy with genomics inventories. The model has the potential and practical capacity to increase biodiversity identifications from a presumed 1% to more than 50% of the total extant. Additionally, inferred physiology of the new species based on their evolutionary history and specific known genes will increase the possibility of identifying previously unknown energy pathways in the lake ecosystem. It will also now be possible to combine findings obtained during the long history of research on the lake with new information to foster new and better ecological interpretations. At the least, the MATBI model will better assist managers in their efforts to conserve biodiversity, the vast majority of which consists of the small organisms that remain the largest void in the story of life on Earth. ■

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Exploring the micro-wilderness of Boston Harbor Islands

By Bruce Jacobson

ISLANDS, LIKE THE GREAT WESTERN WILDERNESS, capture the imagination with their vast complexity. Yet islands are finite; they have a human scale and seem more *knowable* than other places. Thus the idea of inventorying island life may be daunting, but certainly not impossible.

In 2005 Dr. Edward O. Wilson, ecologist and world-renowned philosopher, conservationist, and ant expert, with his Harvard entomologist colleague, Dr. Brian Farrell, began an unprecedented exploration of what Wilson calls "the little things that run the world" at Boston Harbor Islands, a national park area in Massachusetts. Although biological inventories are not new, it is unusual to fully explore "the little things." Most animal inventories focus on mammals, birds, reptiles, amphibians, and fishes. Instead the Boston Harbor Islands effort documents the inhabitants of the islands' micro-wilderness, providing an opportunity to focus on animals that can be examined firsthand, literally in hand. Many of the animals living in the micro-wilderness on the Harbor Islands are so small that, depending on the species, tens, hundreds, or even thousands would fit in the palm of your hand.

One exciting aspect of the five-year Harbor Islands invertebrate project is that it is not limited to a small cadre of scientists. The proximity of the islands to the largest urban population in New England offers the opportunity for many people to explore firsthand, using the park as a natural laboratory. Students, citizen scientists, and amateur naturalists, guided in the field by taxonomic experts, can join in the search for life among the nooks and crannies of the islands.

Many of the animals living in the micro-wilderness on the Harbor Islands are so small that, depending on the species, tens, hundreds, or even thousands would fit in the palm of your hand.

The presence of each species identified is documented in the field through notes, global positioning coordinates, and photography. A comprehensive database will be made available to the public on the Internet, containing all of the field information and images of specimens documented during each of the four planned field seasons. Eventually, scientists will also sequence a fragment of DNA for every invertebrate species collected that can be used for rapid identification as part of a growing international effort to provide such DNA bar codes, as they are known, for all species on Earth.

Research and curatorial aspects of the project are under the direction of Dr. Farrell, professor of biology and curator in entomology at the Museum of Comparative Zoology, Harvard University. Museum collections and literature will be used to identify most specimens, but taxonomists from around the world may be called on to identify any unusual finds. Jessica Rykken filled a postdoctorate position in July with responsibility to further develop the biodiversity inventory.

The 34 islands comprising Boston Harbor Islands national park area (left) vary in size, degree of development, and distance from Boston. They offer both a recreational haven for urban residents and a laboratory in which to learn about natural change and stewardship of the island ecosystem.

In June 2005, Harvard biologist E.O. Wilson (below) and students from Odyssey High School kicked off a five-year project to explore the invertebrates of Boston Harbor Islands. Through intensive, short-term "bio-blitzes," the many project partners hope to gain a strong understanding of the islands' biodiversity, possibly discovering new species and even testing the theory of island biogeography.

Bruce Jacobson, superintendent of Boston Harbor Islands, oversees public outreach efforts about the project. Management of this unique park is coordinated among representatives from the National Park Service, US Coast Guard, Massachusetts Department of Conservation and Recreation, Massachusetts Water Resources Authority, Massachusetts Port Authority, City of Boston Office of Environmental Services, Boston Redevelopment Authority, Thompson Island Outward Bound Education Center, The Trustees of Reservations, Island Alliance, and Boston Harbor Islands Advisory Council.

Partnership liaison Mary Raczko facilitates programs to involve citizens and students in cooperation with Kelly Fellner, supervisory park ranger. The Boston Harbor Islands staff develops traveling museum exhibits, schedules curriculum-based school trips to the islands, coordinates public "bio-blitzes," and facilitates development and distribution of publications and posters. Research learning centers, one at Acadia National Park and another at Cape Cod National Seashore, promote the use of data throughout the academic community for research purposes, exploring ecological questions related to island biogeography, climate change effects, and other possible societal impacts on biodiversity.

Restoring the natural diversity of the islands is a long-term goal of the Boston Harbor Islands Partnership. It will take the focused attention of a generation of scientists and resource managers to accomplish this major endeavor. A key component in the restoration effort is the identification and understanding of all organisms, from the smallest microscopic creatures whose importance is largely unknown to larger organisms whose role in the ecosystem is better understood. Few comparable opportunities exist to explore the interrelationship among all these creatures, large and small. As more details of those relationships come to light, new methods of native species conservation and restoration may also be revealed. ■

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Tomales Bay Biodiversity Inventory: A successful partnership in action

By Ben Becker and Joe Kinyon

THE COAST OF CALIFORNIA IS PRIZED not only for its scenic beauty but also for the abundance of marine mammals and other living things found there. Along the coast, visitors may see whales, sea lions, and birds as well as bobcats and elk. However, there are many plants and animals that are harder to spot. In fact the presence of hundreds of coastal inhabitants was completely unknown until recently. In its third year the Tomales Bay Biodiversity Inventory (TBBI) made considerable progress in the basic but essential task of describing the biodiversity of Tomales Bay, a coastal estuary located on the central California coast approximately 40 miles (64 km) northwest of San Francisco. As of October 2005, the inventory had recorded 2,008 species, a 24% increase from the 1,623 species documented just two years earlier.

Partnership is a big part of the success of this effort. The TBBI is supported by the Tomales Bay Biodiversity Partnership, an organization of community members and scientists dedicated to fostering a deeper understanding of the life of Tomales Bay. Cooperation for research and management of the bay, which abuts land owned or managed by various public and private entities, has been established among more than 40 organizations and individuals, including Point Reyes National Seashore, Golden Gate National Recreation Area, the California Department of Parks and Recreation, and the Marin County Parks and Open Space District. At the watershed level, the Tomales Bay Watershed Council is a collaborative group of organizations and businesses working to protect and restore the waters and lands of the watershed. The Pacific Coast Science and Learning Center, located at Point Reyes National Seashore, supports the inventory by hosting a full-time GIS specialist, a position made possible by a generous grant from the Marin Community Foundation.

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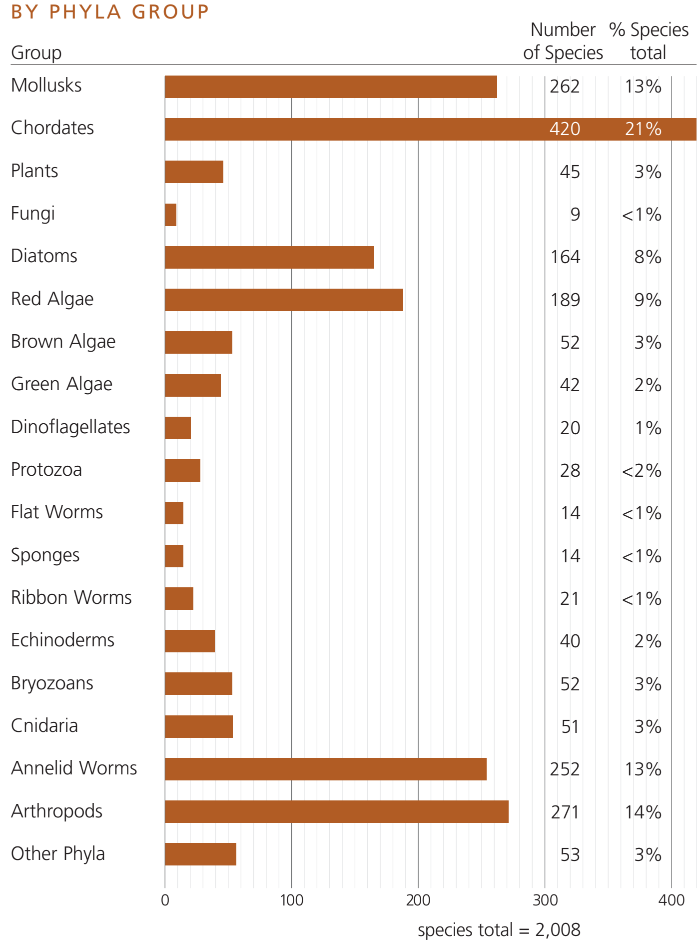
In this context the TBBI coordinates its efforts with partners to combine targeted research and data management activities intended to help inform and guide management efforts. Data management coincides with new data collection and experiments that grow out of ongoing inventories and taxonomic work for fish, marine invertebrates, and algae. Several new research programs are designed to directly inform management. These efforts include research on native oyster population ecology, the impacts of invasive snails on biodiversity, and the effects of algal blooms on native eelgrass, a foundational species that provides forage for many fishes, invertebrates, and waterbirds in the bay.

Tomales Bay, California, is the site of an ongoing biodiversity inventory that includes participation of the Pacific Coast Science and Learning Center at Point Reyes National Seashore, the Golden Gate National Recreation Area, and many

DIVERSITY OF SPECIES IN TOMALES BAY, CALIFORNIA, BY PHYLA GROUP



October 2005

other partner organizations. This view of the bay shows Walker Creek marsh (foreground), Hog Island (left), and the national seashore (background).

The data collection and experimentation have important on-the-ground applications for land managers and local partners. For example, the inventory database is facilitating the identification of species of local interest and their habitats that may require special management or protection. The inventory effort is also providing new information about invasive species and range extensions that frequently occur in marine systems during unusually warm years. For example, during the warmer-than-average summer of 2005, California grunion (*Leuresthes tenuis*), a southern California fish that spawns on sandy beaches during extremely high tides, made its first documented appearance in the bay. This range extension resulted in a new species for the database as well as excitement among anglers and scientists alike.

Further information on the TBBI and the Tomales Bay Watershed Council is available at www.tomalesbaylife.org and www.tomalesbaywatershed.org. The TBBI Web site has a searchable bibliography with more than 500 entries on the ecology and species of the bay. Species lists are available by taxonomic hierarchy to allow users to quickly determine if a particular species occurs in the bay or to examine how biodiversity differs among groups. In the future the TBBI will continue to contribute to documenting and protecting the biodiversity of this special California bay. ■

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Smokies' search for life robust in eighth year

By Becky Nichols

THE ALL TAXA BIODIVERSITY INVENTORY (ATBI) celebrated its eighth successful year in 2005 and continued to advance its goal of discovering all of the species that occur in the 815-square-mile (2,111 sq km) Great Smoky Mountains National Park, which straddles Tennessee and North Carolina. Yet again, the field season was a flurry of activity. The participating ATBI scientists have now documented 3,572 new records for the park and 565 species that are new to science. This brings the total number of new biodiversity discoveries made at Great Smoky Mountains National Park to more than 4,000 since the ATBI began in 1998.

Participating scientists used creative strategies for finding and documenting species. For example, the Coleoptera Taxonomic Working Group (TWIG) conducted a "mega beetle blitz" for two weeks in June. The blitz was an intensive field sampling effort conducted by experts that resulted in several new records for the park. Additionally, four posters by the Coleoptera TWIG, showing beetle blitz results and other ATBI activities in the Smokies, were presented at the Entomological Society of America's annual conference. The total number of beetle species for the park is now 1,804.

ATBI scientists have now documented 3,572 new records for the park and 565 species that are new to science.

A lepidoptera "bio-quest" was held in May, earlier than previous sampling efforts, in hopes of finding those species of butterflies and moths that emerge early in the year. Nearly 400 species were recorded, several of which were new records for the park and one that was also a new family record. An additional effort during this event was the collection of DNA samples from selected specimens. First, one leg from each butterfly or moth species was collected and frozen in liquid nitrogen for "DNA bar coding." The bar coding process is based on the quick assessment of the mitochondrial DNA in the specimen. Comparisons can then be made of this DNA information with other closely related species; these comparisons assist with final species determination and phylogenies. Finally, the remainders of the moths and butterflies selected for DNA analysis were sent to the cryogenic storage facility at the American Museum of Natural History in New York to archive tissues of these species in a repository for future generations.

One measure of the continued success of the ATBI is that scientists remain enthusiastic about the project and continue to seek funding for research within the park. For example, in 2005 two National Science Foundation grants were awarded to conduct ATBI research. Also, the mini-grant program awarded $52,000 to support ATBI

The All Taxa Biodiversity Inventory celebrated its eighth successful year in 2005 and continued to advance its goal of discovering all species that occur in Great Smoky Mountains National Park. A "fern foray" was part of the flurry of activities that took place in the 2005 field season. These periodic efforts to determine the distribution of fern species in the park rely heavily on volunteers. The volunteers pictured are taking a GPS reading before beginning the fern foray in August at Clingmans Dome.

Great Smoky Mountains National Park hosted a lepidoptera "bio-quest" in May 2005. The sampling effort was conducted sooner in the year than in previous seasons in hopes of finding those species of butterflies and moths that emerge early in the year. Nearly 400 species were recorded, including the Pandorus sphinx moth (*Eumorpha pandorus*) pictured at top.

educational projects, including teacher workshops and community outreach. These funds also sustained research projects covering a wide range of taxonomic groups, including fungi, tardigrades, slime molds, flies, beetles, thrips, water mites, and algae. Some of this funding was also used to conduct blitz-type collecting activities.

The ATBI has uncovered and will continue to uncover the amazing range of life in Great Smoky Mountains National Park. As the inventory matures, it also provides important lessons for how parks can encourage scientists to conduct research in national parks and advance technology that improves human understanding of the natural world. ■

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Slime mold inventory: Studying one group of species across the National Park System

By Paul Super

AN ALTERNATIVE APPROACH to the "all species–one park" model now applied to natural resource inventories in national parks is to conduct a comprehensive inventory of a single taxonomic group of species across representative sites of the entire National Park System. The National Science Foundation (NSF) has provided an opportunity to pilot this alternative approach, and the taxon chosen to be surveyed in the first round of the NSF Planetary Biodiversity Inventory Grants is eumycetozoans (you-my-SEE-tuh-zo-ans), a group of organisms saddled with the unfortunate common name of "slime molds."

This inventory approach is an efficient way of addressing certain groups of species of great concern and involving smaller park units that cannot support a lot of researchers at one time. Our system of national park units represents a nearly comprehensive sample of the major habitat types in North America. A survey of representative park sites throughout the country could provide an in-depth understanding of the distribution of the majority of organisms on the continent. The laboratory of Drs. Steve Stephenson and Fred Spiegel at the University of Arkansas is heading up the grant. This lab has the capacity to identify the samples that such a broad-based survey would generate at no additional cost to the parks.

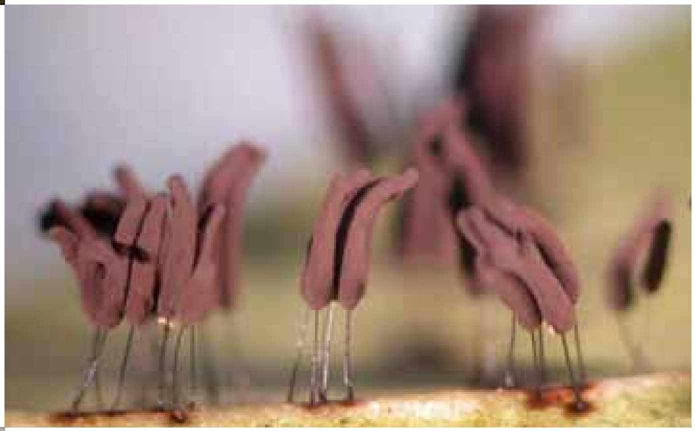
A survey [for particular taxa in] representative park sites throughout the country could provide an in-depth understanding of the distribution of the majority of organisms on the continent.

Eumycetozoans are easy to culture from soil and various types of dead plant material. Larger species can be located and identified by their fruiting bodies. Research to date indicates that the diversity of slime molds in a habitat may decline with such environmental threats as acid deposition, global climate change, and increased domination by exotic plants. Eumycetozoans may also be good indicators of the health of a soil ecosystem stressed by a toxic waste spill, incidental application of fertilizers or pesticides from neighboring private lands, or habitat isolation by development outside a park's borders. The first step in appreciating eumycetozoans is to know what we have in our national parks.

At the end of 2005, 23 park units, from Denali in Alaska to Everglades in Florida, were participating in this project and 11 research learning centers were assisting with its coordination. The inventory is conducted by different methods at different sites to determine what model works best. In Great Smoky Mountains National Park (North Carolina and Tennessee), most of the collecting was done by professional taxonomists. At Tallgrass Prairie National Preserve (Kansas), after National Park Service staff provided orientation, volunteers collected material and sent it to the University of Arkansas laboratory for culturing. At Wind Cave National Park (South Dakota), park staff collected samples while in the field for other purposes without a significant addition to their workload.

Theresa Yednock of Congaree National Park, South Carolina, examines a specimen of the slime mold *Arcyria cinerea* during the June 2005 training held at Great Smoky Mountains National Park. Twenty-three national park units are participating in an alternative biodiversity inventory that involves multiple parks surveying one taxonomic group.

Metatrichia vesparium (above) is one of the more common myxomycetes, one of three groups of slide molds, to be encountered in early autumn. It typically fruits on the dead bark of decaying logs.



The fruiting bodies of *Stemonitis herbatica* typically occur on living plants, a common substrate for most myxomycetes. Certain groups of slime molds could serve as biological indicators. For example, some species that occur on the bark of living trees are absent in areas of high pollution, leaving the bark surface almost devoid of slime mold.

The distinctive netlike fruiting bodies of *Hemitrichia serpula* (left) can be found on decaying wood and bark in late summer.

In June 2005, partners from 14 park areas attended a "Train the Trainers" workshop funded by the US Environmental Protection Agency at Great Smoky Mountains National Park to give them the expertise to oversee inventory work at their own parks. One such trainee, elementary school teacher Melissa Forsythe of Big Bend National Park (Texas), leads her students to collect samples—an outstanding educational experience with a real-world application. Images of fruiting bodies cultured by the students can be uploaded to a data server where Stephenson and his team can either make the identifications or tag them for additional examination.

The National Park Service is charged with preserving outstanding examples of America's natural, cultural, and recreational resources for the enjoyment, education, and inspiration of future generations. Yet we are only just beginning to understand the complex natural systems in our care in ways that will help us successfully manage them for the future. The Natural Resource Challenge initiative has helped to document the types, abundance, and distribution of species in national parks by funding a comprehensive inventory of vertebrates and vascular plants. To understand other life-forms, Great Smoky Mountains National Park and Point Reyes National Seashore have embarked on comprehensive inventories of all species within all or part of their park boundaries, not just the vertebrates and vascular plants. Other parks are also in the process of establishing their own all-taxa inventories.

The eumycetozoan survey is yet another method of adding to our knowledge of life on Earth and in our national parks, and is scheduled to run through 2007. By then, in addition to understanding the diversity and biogeography of eumycetozoans, project coordinators expect to know what it would take in terms of funding, staff, volunteer training, and methodologies to conduct similar multipark inventories of native bees, land snails, and other taxa that provide significant ecological services to the national parks and to the world as a whole. ■

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River of research in Olympic National Park

By Jerry Freilich

Two dams along the Elwha River will be dismantled beginning in 2008, giving researchers a rare opportunity to study the trajectory of river restoration at Olympic National Park. The Elwha Research Consortium helps coordinate research and develops educational materials about the efforts of the many scientists, community members, and students involved in these projects.

THE ELWHA RIVER RESEARCH CONSORTIUM took a big step forward in early 2005 when the National Science Foundation awarded two grants, totaling $1 million, to consortium partners. The funds will provide support for two projects and enable the consortium to become a recognized entity that facilitates, coordinates, and promotes research and education efforts along the Elwha River in Olympic National Park, Washington.

Because all of the land above the upper dam is within the national park, the opportunities for research in an otherwise pristine ecosystem will be unique.

The timing is right for such a venture because two hydropower dams on the Elwha River in Olympic National Park are scheduled for removal beginning in 2008. This effort will be the largest dam removal ever attempted and one of the largest river restoration projects of all time. This congressionally approved $184 million project will permit five species of salmon to return to waters they have been locked out of for more than 90 years. Because all of the land above the upper dam is within the national park, the opportunities for research in an otherwise pristine ecosystem will be unique. Unfortunately, removing the dams and protecting drinking water for the nearby city of Port Angeles will use nearly all the appropriated funds, so the budget contains little for education or research.

Enter the Elwha consortium. The two grants received in 2005 will assist the consortium in coordination of research efforts that enable Olympic National Park to be used as a living laboratory. Some of the questions to be explored are how long it will take for natural spawning populations to reestablish themselves in a pristine river that has been blocked for almost a century, and how hatchery fish will interact with wild fish coming up the river. Other important questions concern the transport of sediments out of the river and their effects on both domestic drinking water and the fishery. Perhaps the most important question the Elwha consortium may help answer is the relative importance of marine-derived nutrients to forest ecosystems. Using isotopic signatures to determine the origin of biomass, researchers can determine the quantitative and qualitative differences between rivers without salmon and rivers that have salmon. As time runs out before demolition of the Elwha dams begins, the Elwha Research Consortium is an example of the synergy possible in a group of like-minded and determined scientific partners to capitalize on the unique opportunity presented in Olympic National Park. ■

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An ecological monitoring parable: System-level changes following the loss of island foxes at Channel Islands National Park

By Cathy Schwemm, Charles Drost, and John Orrock

BIOLOGISTS AT CHANNEL ISLANDS NATIONAL PARK, California, are learning that the absence of the endemic island fox (*Urocyon littoralis*) from San Miguel and Santa Rosa Islands also affected other species and ecological processes, resulting in a unique natural experiment of the effects of removing a top predator from an ecological system. Because Channel Islands National Park had a broad-based natural resources monitoring system in place, park staff and partners were able to document dramatic changes in populations of other species that occurred during the fox decline, yielding surprising insights into island ecosystems. This knowledge is important not only to the National Park Service for future protection and management of the foxes, but also to the larger scientific community, as it might relate to ecological questions regarding the role of predators in structuring ecosystems.

The ecological lessons learned, particularly on San Miguel Island, may be more evident and distinct because of the simplicity of this system. Only two mammals are native on San Miguel: the island fox and an endemic subspecies of deer mouse (*Peromyscus maniculatus streatori*). Historically, foxes were the dominant predator of the mice, and mice one of the foxes' most important food sources. Data from the park's vertebrate monitoring program, ongoing since 1993, showed a sudden and dramatic increase in mouse densities beginning in 1998, the year the fox population on that island was effectively extirpated. These results strongly suggest that foxes were a regulating factor of mouse populations, and their absence consequently allowed mice to increase to higher levels. The data also revealed that mouse populations decreased in the absence of foxes to numbers lower than previously recorded, likely because of a population crash driven by density-dependent regulation within the mouse population.

The loss of foxes has also had indirect effects on elements of the island ecosystem. Before 1998, counts of barn owls (*Tyto alba*) along a 6-mile (9 km) transect never exceeded 10 individuals, while recent counts have been as high as 28. Barn owls are specialist predators of small rodents, and likely responded to the increases in mouse numbers. Short-eared owls (*Asio flammeus*) and northern harriers (*Circus cyaneus*) were rare to uncommon winter visitors before 2000. Both species have since established resident populations, and in 2002, US Geological Survey biologists documented the first known successful nesting of harriers on the island. The eggs and chicks of these ground-nesting species historically would have been prey for foxes but survive when foxes are absent.

Finally, researchers collaborating with the National Center for Ecological Analysis and Synthesis and the University of California–Santa Barbara are investigating whether mouse behavior has changed on the island in response to reduced predation risk. Prey species are known to change foraging habits based on their

The extirpation of island foxes from San Miguel Island, one of five islands within Channel Islands National Park, resulted in ecosystem-level changes. The simplicity of the island system may have helped facilitate observation of these changes, though without monitoring, the perturbations may not have been detected.

Mammal inventory surprises managers at Vicksburg National Military Park

By Jennifer M. Linehan, Michael Mengak, and Kurt A. Foote

VISITORS ENTERING THE ILLINOIS MONUMENT, a neoclassical edifice built in 1906 in commemoration of the Illinois soldiers who served under General Ulysses S. Grant during the Civil War Siege of Vicksburg, are usually unaware that they are entering a bat cave as well. The domed structure is open at the top and features sculpted crevices within which big brown bats (*Eptesicus fuscus*) have made their home for years. These bats seem inured to the regular disturbance of human voices echoing around the chamber and return to the monument each morning following their nightly foraging flights.

Until FY 2005, staff at the park was unsure which species of bat inhabited the memorial. This data gap has been filled thanks to the efforts of a University of Georgia (UGA) graduate student working on a formal and comprehensive mammal inventory for the park. The University of Georgia is a partner institution within the Gulf Coast Cooperative Ecosystem Studies Unit. This study completes Vicksburg's vertebrate fauna inventories coordinated by the Gulf Coast Inventory and Monitoring Network using Natural Resource Challenge funding. It also completes the last of the park's 12 basic natural resource inventories prescribed by the Challenge initiative, giving managers information about the type, distribution, and abundance of a variety of natural resources at this "cultural" park. Among the findings are two new bat species records for Warren County: the hoary bat (*Lasiurus cinereus*) and the Seminole bat (*Lasiurus seminolus*), both foliage-roosting species.

In addition to identifying new species and the nocturnal inhabitants of the Illinois Monument, the mammal inventory has yielded other pertinent information regarding bats. A radiotelemetric study was implemented to investigate the roosting structures of evening bats (*Nycticeius humeralis*) in the national military park. Though the sample size of this study is small, preliminary results have shown that the majority of roosting structures used by radio-tagged evening bats were located in utility poles. This is of interest to park managers because it may suggest that tree roosts are limiting for this species, and that evening bats are adapting to an increasingly developed landscape. This example highlights the ideal situation of this urban park, which commemorates Civil War history, as a laboratory for studying the effects of habitat alteration upon wildlife. ■

The mammal inventory at Vicksburg National Military Park identified two new species of bats for Warren County, including the hoary bat. A pregnant female is pictured here.

The Illinois Monument and other artificial structures are important roost sites for bats at the national military park.

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perception of risk, potentially increasing or decreasing impacts on food sources. Specifically, this research concerns whether higher mouse numbers and altered foraging patterns stemming from fox extirpation are having negative impacts on native island plants.

Two important lessons were learned from monitoring critical natural resources at Channel Islands National Park, even in the absence of identified threats. Most important, monitoring data revealed the sharp decline in fox populations. Without these data, one and possibly two subspecies of fox almost certainly would have gone extinct. Moreover, because monitoring programs were also in place for vegetation, land birds, and other resources, data from these programs were collected fairly easily and are now available to help interpret the impacts of the loss of foxes and make informed decisions regarding long-term fox conservation. Given the speed and severity of the fox decline, the ecosystem-level effects following loss of the foxes probably would have gone undetected without this monitoring.

The loss of the island fox from these insular systems was clearly undesired and, one hopes, temporary, but did provide an opportunity to observe ecosystem changes resulting from a large perturbation. National parks can be unique natural laboratories; however, the level of success of both planned and unplanned ecological experiments lies largely in the ability of parks to have natural resource monitoring and research programs in place prior to potential impacts. In future years, biologists and partners at Channel Islands National Park hope to glean more understanding of the ecology of the fox and the larger island ecosystems as more data are collected and wild populations of foxes are restored. ■

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The significance of dating Sierra Nevada caves

By Greg Stock

RESULTS PUBLISHED IN 2005 from ongoing cave research in Sequoia and Kings Canyon National Parks shed light on the landscape evolution of the Sierra Nevada. This study also refines a method for reliably dating cave development. When dated, caves indicate rates of river incision, or downcutting, the primary erosional process governing the pace at which landscapes evolve. Although river incision could be due to climate change (i.e., increased precipitation increases the size of a river and its erosional power), results of this study suggest that tectonic uplift is the driver in the Sierra Nevada. As rivers cut deeper into their canyons, solution caves—which form at the water table or river level—are left perched in the steep canyon walls, far above modern rivers. Hence, caves increase with age from valley floor to rim and record the history of river downcutting in the southern Sierra Nevada. Yet determining rates of landscape evolution in this region first requires establishing the ages of caves that have recorded landscape changes over time.

This rapid erosion may relate to a globally recognized shift in climate …, but these new data strengthen the case for tectonically driven uplift.

As with any cave analogy, however, what on the surface seems simple may become complicated at depth. That is, caves are difficult to date because by definition a cave is a void, and how does one date empty space? Geologists usually determine the age of a cave by the materials deposited in it (e.g., sediments, bones, and speleothems), but dating is constrained by the oldest deposits, which may be far younger than the cave itself. To tackle this problem, Greg Stock, a researcher from the University of California–Santa Cruz, collected sand and gravel samples from 14 caves from the Sierra Nevada and dated them using cosmogenic burial dating. Cosmic rays striking Earth's surface create rare isotopes such as aluminum-26 and beryllium-10. So long as rocks stay on the surface, these isotopes are produced in them. The longer the rocks are exposed at the surface, the more cosmic rays accumulate in them. When these rocks become deeply buried, however, such as when sand and gravel wash into a cave, they are shielded from cosmic rays and the isotopes cease to accumulate. Instead they begin to decay radioactively at a rate determined by their half-life, which scientists can measure. The half-life of aluminum-26 (0.73 million years) is roughly half that of beryllium-10 (1.6 million years), so the ratio $^{26}Al/^{10}Be$ decreases exponentially with time as sand and gravel remain within the cave.

Cosmogenic burial ages from caves in Sequoia and Kings Canyon National Parks reveal a pulse of river incision 1–3 million years ago. This rapid erosion may relate to a globally recognized shift in climate around this time, but these new data strengthen the case for tectonically driven uplift. As the mountains rose, the river gradients steepened and the rivers cut down more quickly to reach a new equilibrium state. The dated caves suggest that the Sierra Nevada topography is a product of two uplift events, the first nearly 100 million years ago and the second much more recently, in the past 3–10 million years. ■

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In a cave perched high above a valley floor in Kings Canyon National Park, researcher Greg Stock collected sand and gravel, which he analyzed using a recently developed method called cosmogenic burial dating. Sediments buried in this cave indicate an age of 2.4 million years. Cave age provides evidence for the timing and rate of uplift of the Sierra Nevada.